## Addendum to Highway Research Record 341

The Board inadvertently published the wrong committee sponsorship of the papers published in Highway Research Record 341. Discussions by F. P. Nichols, Jr., and Glenn Balmer of the paper, "Predetermining the Polish Resistance of Limestone Aggregates, by W. Cullen Sherwood and David C. Mahone, pages 1-10, which had been submitted in accordance with the Board's regulations and approved for publication, were omitted. This Addendum contains these materials and should be inserted in your issue of Highway Research Record 341.

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batch of aggregate as was used in the bituminous concrete placed in the test track. This has not afforded a perfect correlation between skid resistance and either the total or the specific size fraction of insoluble residue, but it has made it clear that general relationships do exist, as will be shown.

The plan recognized that in ½ in. top size mixes the character of the largest particles exerts the most influence on the polish susceptibility of the surface. Therefore, the acid solubility test was conducted only on the plus No. 8 fraction of the grading. The method used to obtain and analyze the insoluble portion was essentially that described in an earlier paper (13): After the soluble carbonates were completely digested in diluted HCl, the residue was filtered, washed, dried, weighed, and then subjected to wet sieve analysis. No effort was spent on hydrometer analysis because it had been concluded earlier that the character of insolubles finer than 200 mesh was unlikely to affect polish resistance significantly.

A total of 24 carbonate rock samples were so tested. Of these, 22 were also subjected to the following more detailed analysis. A portion was ground in the laboratory ball mill until all would pass a 50 mesh, and the ground material was split into 2 parts; one was tested for maximum specific gravity, and the other by X-ray diffraction to detect the presence of the dolomite mineral.

## Results of Test Program

Table 7 gives the findings on all 3 mix types and all 24 carbonate rocks.

Emphatic warning must be given that the BPT skid numbers obtained with NCSA's tester are relative to each other only. They may be higher or lower than BPT numbers that might have been obtained by other standard testers. Variables between test track installations may be present, but these were minimized by adjusting the tester each time to check as closely as possible with previous average readings on 4 standard surfaces. A roundabout correlation was once made that indicated that an NCSA skid number of 48 was roughly equivalent to the critical stopping distance number of 40 cited by

TABLE 7

TEST RESULTS OF ALL-CARBONATE AGGREGATES, NO BLENDS, AFTER 50,000 WHEEL PASSES

| Date[a] | Aggregate | BPT Skid Number: Grading A ½-in. Dense | | Grading B ⅜-in. Open | | Grading C[b] ½-in. Very Open | | Maximum Specific Gravity | Dolomite[c] (percent) | Acid Insolubles in -½ in. + No. 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Original | Final | Original | Final | Original | Final | | | All +200 | Sand |
| Aug. 1968 | Penn. 1 | 73 | 70 | 78 | 68 | 80 | 67 | 2.72 | None | 49 | 34 |
| Aug. 1968 | Tenn. 2 | 74 | 69 | 81 | 69 | — | — | 2.76 | Trace | 32 | 27 |
| Aug. 1968 | Va. 3 | 69 | 58 | 76 | 58 | 76 | 58 | 2.76 | Trace | 30 | 18 |
| Jan. 1969 | N.Y. 2 | 72 | 57 | — | — | — | — | 2.83 | Major | 15 | 13 |
| Jan. 1969 | N.Y. 3 | 72 | 56 | — | — | — | — | 2.84 | Major | 17 | 11 |
| Aug. 1968 | N.Y. 1 | 64 | 56 | — | — | — | — | 2.71 | Minor | 36 | 5 |
| Aug. 1968 | Md. 1 | 65 | 54 | 72 | 56 | 73 | 48 | 2.74 | 20 | 9 | 7 |
| July 1969 | Me. 1 | 73 | 51 | — | — | 71 | 51 | — | — | 39[d] | 12[d] |
| Aug. 1968 | Tenn. 1 | 60 | 49 | — | — | — | — | 2.84 | Major | 8 | 4 |
| Aug. 1968 | Ga. 1 | 69 | 47 | — | — | — | — | 2.71 | Trace | 2 | 2 |
| Jan. 1969 | Penn. 3 | 62 | 47 | — | — | — | — | 2.84 | Major | 8 | 4 |
| Aug. 1968 | Tenn. 3 | 56 | 46 | 62 | 41 | — | — | 2.85 | Major | 4 | 2 |
| Aug. 1968 | Va. 2 | 58 | 45 | — | — | — | — | 2.82 | Major | 5 | 2 |
| Aug. 1968 | Va. 1(old) | 59 | 44 | — | — | — | — | 2.85 | Major | 3 | 2 |
| July 1969 | Ill. 1 | 65 | 44 | — | — | 64 | 48 | — | — | 24 | 2 |
| Aug. 1968 | Penn. 2 | 55 | 43 | — | — | — | — | 2.82 | 40 | 2 | 1 |
| Jan. 1969 | Penn. 5 | 66 | 43 | — | — | — | — | 2.87 | Major | 3 | 1 |
| Nov. 1968 | N.Y. 4 | 65 | 43 | — | — | — | — | 2.84 | Major | 8 | 4 |
| Jan. 1969 | W. Va. 1 | 70 | 42 | — | — | — | — | 2.72 | Minor | 11 | 9 |
| Jan. 1969 | Penn. 6 | 64 | 42 | — | — | — | — | 2.85 | 40+ | 1 | 1 |
| Feb. 1969 | S.C. 2 | 71 | 41 | — | — | — | — | 2.72 | None | 3 | 3 |
| Jan. 1969 | Penn. 7 | 61 | 38 | — | — | — | — | 2.76 | 20 | 3 | 2 |
| Aug. 1968 | Va. 1(new) | 60 | 37 | — | — | — | — | 2.74 | Minor | 1 | 1 |
| Jan. 1969 | Ohio 1 | 63 | 33 | — | — | 64 | 27 | 2.72 | None | 4 | 4 |

[a]Grading A only. [b]40,000 wheel passes. [c]Determined by X-ray diffraction. [d]Metamorphosed, insoluble grains very friable.

TABLE 10

TEST RESULTS OF GRADING C, ½-IN. VERY OPEN MIXES WITH BLENDING AGGREGATES AFTER 40,000 WHEEL PASSES

| Aggregate[a] | | Final BPT Skid Number | | |
|---|---|---|---|---|
| Primary | Blending | Primary Aggregate Alone | Blending Aggregate Alone | BPT Value Blend |
| Penn. 5 | | 42 | | |
| | Penn. 1, carbonate rock | | 67 | 61 |
| | Va. 5, granitic rock | | 52 | 50 |
| | Ala. 1, slag | | 48 | 47 |
| | Md. 3, siliceous gravel crushed | | 46 | 48 |
| Ohio 1 | | 27 | | |
| | Penn. 1, carbonate rock | | 67 | 61 |
| | Va. 5, granitic rock | | 52 | 52 |
| | Md. 3, siliceous gravel crushed | | 46 | 48 |
| | Ala. 1, slag | | 48 | 44 |

[a]The 50 percent of primary aggregate met simplified practice grading No. 9; the blending aggregate was slightly coarser, meeting No. 8, with the result that 88 percent of the plus No. 4 particles were from the more polish-resistant rock and 88 percent of the minus No. 4 were from the primary carbonate rock.

Sherwood and Mahone, but this relationship has never been confirmed. Further, any such relationship would no doubt be different for the different surface textures resulting from gradings A, B, and C. Perhaps the only statement that could be made with real confidence would be that, for a given gradation, the higher the BPT number is the higher the skid resistance will be.

Notwithstanding these statements, the relationships tabulated are believed to have real value in explaining the role of rock type and composition in the complex picture of skid resistance. Under each grading given in Table 1 is shown an original test value (obtained after initial wear and cleaning) and a final test value (obtained at the termination of the test, usually 50,000 wheel passes). The insoluble residues from the coarse aggregate particles are expressed as "all +200" and "sand," and are percentages by weight after being digested in HCl, washed, and sieved. Sand refers to the minus No. 8 and plus No. 200 material in the residue.

Table 8 gives the applicable test data obtained on the 13 noncarbonate aggregate mixes. Only one of these, the crushed siliceous gravel, is noted to have been tested in all 3 gradings.

Table 9 gives the effectiveness of blending various percentages of the more polish-resistant aggregates with 7 of the less polish-resistant carbonate aggregates in the plus No. 4 fraction of the grading A mix. Because this mix had only 38 percent plus 4, the substitution of ⅓ of this fraction was equivalent to roughly 13 percent of the total aggregate—⅔ to roughly 25 percent. Note that the figures in the columns "Primary Aggregate Alone" or "Blending Aggregate Alone" were transposed from Tables 7 or 8 as applicable.

Table 10 gives similar data for open-graded mixes B and C, indicating the feasibility in certain areas of using 50 percent of a more readily available carbonate aggregate in an adequately skid-resistant, open-graded mixture. The note to Table 10 explains how the effectiveness of the blending aggregate was increased by ensuring that it compose most of the larger particles in the mix.

## Discussion of Results

Figure 5 shows the relationship between acid-insoluble, sand-sized constituents in the coarse fraction of all-carbonate mixtures and the final BPT number obtained after polishing. The line shown represents the least squares regression computed in the

reported to have either a major percentage of dolomite or as much as 40 percent all had specific gravities of 2.82 or more. This seems to indicate that a fair estimate of the percentage of dolomite may be obtained from the much simpler test for maximum specific gravity without the necessity of X-ray diffraction analysis. In this connection, it appears that the NCSA data confirm those cited by Sherwood and Mahone to the effect that there is a lack of any trend between calcite dolomite percentages and skid resistance.

## General Indications From NCSA Data

The studies conducted by NCSA since May 1968 seem to definitely indicate the following:

1. Many carbonate aggregates may be used with as great a degree of safety as many slags or so-called hard rocks in the design of skid resistant surfacing mixes.
2. The test for acid-insoluble constituents provides a good preliminary indication of the potential polish susceptibility of carbonate rock deposits used or being considered for use in the production of aggregates. The test should be performed on the coarse particles, and judgment should be used in deciding whether total insolubles or only sand-sized insolubles should be considered the best indicator in the case of particular rocks.
3. Careful blending of uniformly high friction aggregates is both practically and economically feasible in upgrading to an acceptable level the skid resistance of mixes containing from 50 to 87 percent relatively pure carbonate aggregates normally expected to be polish susceptible.

## Acknowledgment

Appreciation is expressed to the G. and W. H. Corson Company for conducting the X-ray diffraction tests.

## References

13. Gray, J. E., and Renninger, F. A. The Skid Resistant Properties of Carbonate Aggregates. Highway Research Record 120, 1965, pp. 18-34.
14. Goldbeck, A. T., and Gray, J. E. Skid Proofing of Asphaltic Concrete Pavement Surfaces. Crushed Stone Jour., National Crushed Stone Assn., March 1969.

GLENN BALMER, Federal Highway Administration—The authors' use of the acid-insoluble residue test for predetermining the skid-resistance characteristics of limestone aggregate shows application of a simple and pertinent procedure. They are to be congratulated for a fine paper.

It is significant to note in another paper (15) that the friction characteristics of portland cement concrete pavement with limestone in the surface course also increased with the increase in acid-insoluble residue content of the limestone. The test results are similar to those of Sherwood and Mahone.

Furthermore, the skid resistance of the pavement was increased by blending of aggregates that increased the siliceous particle content of the surface aggregates as Nichols has commented in his discussion.

The acid-insoluble residue determination is a convenient means of predetermining potential skid resistance of pavements and should be formulated as a standard procedure.

## Reference

15. Laboratory Test Results of the Skid Resistance of Concrete. Jour. of Material, Sept. 1966.